

COMPOSITIONS OF PARTLY ALTERED OLIVINE AND REPLACEMENT SERPENTINE IN THE CM2 CHONDRITES QUE93005 AND NOGOYA: IMPLICATIONS FOR SCALES OF ELEMENTAL REDISTRIBUTION DURING AQUEOUS ALTERATION.

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Introduction: Some phyllosilicates in CM carbonaceous chondrites formed by aqueous alteration of anhydrous precursor phases (e.g., [1-3]). Although broad trends in the compositions of hydrous phyllosilicates are recognized and believed to be related to trends in degree of aqueous alteration [2,4], details of the reactions that formed specific secondary minerals remain obscure.

This paper reports compositional relationships between remnants of partially pseudomorphically (or alteromorphically; terminology of [5]) replaced silicates and their alteration products (serpentine) in the CM2 chondrites QUE93005 and Nogoya [6] and compares both with previously published results for Allan Hills 81002 [7]. By focusing on serpentine formed from known reactants (olivines), and on only those instances in which some of the reactant silicate remains, direct compositional relationships between reactants and products, and the elemental mobility required by the reactions, can be established.

Results: QUE93005. QUE93005 (CM2; [8]) is not discernibly brecciated at thin-section or hand-specimen scales. Chondrules are abundant. Most olivine-bearing objects are subrounded to rounded, and exhibit elliptical to circular cross-sections in thin-section. Most also have fine-grained rims visibly identical to "accretionary" rims noted in carbonaceous chondrites interpreted by some as "primary accretionary rocks" [3]. Olivine compositions ranging from Fo₇₇ to Fo₉₉ were observed partially replaced by serpentine in QUE93005; more fayalitic but unreplaced olivine also occurs. Fayalitic olivines are replaced pseudomorphically, with replacement beginning along crystal boundaries and progressing inward (centripetal replacement [5]). Most serpentine replacement of forsteritic olivine forms meshwork serpentine, initiated along fractures traversing olivine crystals; some serpentine partially replacing forsteritic olivine pseudomorphically was also observed. Fayalitic olivine is more extensively replaced than forsteritic olivine. Despite the broad range of reactant olivine compositions, serpentine meshworks across, and pseudomorphic partial replacements of, olivine in QUE93005 have a narrow range of Fe/(Fe+Mg) (molar) ratios, around 0.28±0.03, regardless of the composition of the reactant olivine.

Nogoya. Nogoya is texturally complex and interpreted to be brecciated; previous work reported alteration strongly resembling terrestrial serpentinization [1]. Olivine compositions ranging from Fo₆₅ to Fo₉₉ were observed in Nogoya [6], as is common in CM chondrites in general and as previously reported for Nogoya. Serpentine meshworks across, and replacement rims on, olivine have a narrow range of Fe/(Fe+Mg) (molar) ratios, around 0.20±0.02 (Fe corrected for the presence of finely disseminated sulfides), regardless of the composition of the reactant olivine [6]. The composition of replacement serpentine in Nogoya is identical to the mode in the large range of serpentine compositions in Nogoya matrix and rim material [2].

Stoichiometric replacement reactions were written based on the assumption of constant solid volume before and after reaction. Formation of serpentine of the observed uniform alteromorph composition from olivine that is more forsteritic than Fo₈₈ required importation of Fe (in excess of the amount required to form finely disseminated sulfides). Formation of serpentine of the same composition from olivine that is more fayalitic than Fo₈₈ released excess Fe, which was either exported or taken up as discrete sulfides [6].

Comparison with ALH81002. ALH81002 has been described as an unbrecciated "primary accretionary rock" [7]. In ALH81002, all silicate-replacement (i.e., chondrule and matrix aggregate) serpentines (including those formed from compositionally diverse olivines, orthopyroxene, clinoenstatite, and augite) are uniformly Mg/(Fe+Mg) = ~0.50-0.55 (wt%), regardless of the reactant mineral, but different from serpentine replacing glass Mg/(Fe+Mg) = ~0.3 (wt%) [7]. (Glass commonly exhibits alteration to phyllosilicates before other phases in CM chondrites, and phyllosilicates after glass commonly differ compositionally from phyllosilicates after other phases, e.g., [7,9].) ALH81002 replacement serpentines are similar in composition to serpentines in the texturally similar QUE93005 (Fe/(Fe+Mg) (molar) ~0.3). Replacement serpentines in QUE 93005 and ALH81002 are significantly more Fe-rich than those in Nogoya. (ALH81002 and QUE93005 apparently contain a larger proportion of chondrules and matrix silicate aggregates than Nogoya.)

Discussion: Nogoya is brecciated. Discrete clasts contain matrix serpentine with compositions that fall within the range for matrix serpentine in surrounding material. However, some discrete identifiable clasts have narrow ranges of matrix serpentine compositions relative to the entire range of matrix serpentine compositions in Nogoya. This suggests that individual clasts may have experienced only a narrow subset of the full range of serpentine-forming conditions. The broad range of matrix serpentine compositions in this brecciated meteorite may have resulted from mixing of materials from source regions that produced different serpentine compositions in different regions. Alternatively, different clast and matrix serpentines may have formed from compositionally different precursors (e.g., [7,9]), possibly *in situ*, in which case matrix composition provides little information about scales of mixing and/or homogenization, either during assembly of the breccia or during aqueous alteration.

Replacement serpentines with the narrow range of compositions were observed in multiple objects in a single Nogoya thin section. These replacement serpentines are identical in composition to previously reported Nogoya Mg-serpentines that also formed meshworks replacing olivine [1]. If some or all replacement-serpentine analyses are from different fragments in the Nogoya breccia, then the entire source region for all Nogoya fragments was characterized by identical replacement-serpentine compositions. This could be due either to (1) alteration of all fragments *in situ* after assembly of the breccia, or (2) alteration prior to assembly, with altered fragments being derived from a source region in which replacement serpentines of a single composition formed from compositionally diverse olivine precursors. In the former case, the environment for replacement-serpentine formation was chemically homogenous on the scale of the Nogoya meteorite itself (order 10 cm). In the latter case, the environment for replacement-serpentine formation was chemically homogenous on the scale of the entire source region from which fragments (containing replacement serpentines) were derived, and no fragments from regions producing other replacement-serpentine compositions were mixed into the Nogoya breccia.

Implications: (1) Importation of Fe is required in some pseudo/alteromorphs in each of the three CM chondrites, and Fe exportation is required in others, suggesting that secondary-mineral composition depended little on elements supplied locally by the reactant mineral and more strongly on external factors such as solution composition.

(2) Intrameteorite homogeneity of replacement serpentine exists in each CM chondrite, regardless of the composition of the reactant olivine. This strongly

suggests that the aqueous medium driving the replacement reaction was compositionally uniform on scales much larger than individual olivine crystals, chondrules, or clasts in each CM meteoroid.

(3) QUE93005 and ALH81002 olivines altered to serpentine in geochemically similar environments; Nogoya altered in a geochemically different setting.

(4) If the Nogoya meteoroid was assembled from fragments containing previously altered olivine (e.g., pre-accretionary alteration, or alteration prior to extensive brecciation), uniform serpentine compositions suggest that the altering medium must have been compositionally homogenous over a vast volume of the Nogoya source region. Also, subsequent mixing of clasts from this source region with fragments from sources with different Mg-serpentine compositions is precluded. Differences in phyllosilicate compositions in these CM2s, and in other alteration-related parameters in different CM chondrites [2,4], militate against this interpretation. On the other hand, it would be easy for the aqueous medium to be homogenous on the centimeter to decimeter scale if pervasive aqueous alteration of all fragments took place largely after assembly of reactant materials into the present rock, and subsequent to most major brecciation and mixing of clasts.

(5) Intermeteorite heterogeneity of both replacement [6,7] and chondrule-rim and matrix [2,4] serpentine compositions between different CM2 chondrites implies larger-than-meteoroid heterogeneity of the CM aqueous alteration environment. One consequence is that different CM chondrites have *different* threshold olivine compositions for the transition from Fe-importer to Fe-exporter.

It remains to be established whether larger-than-meteorite-scale heterogeneity in the alteration environment was due to different CM chondrites sampling (a) different spatial regions of a large spatially heterogeneous alteration environment, (b) a single temporally evolving aqueous alteration system at different stages of its chemical evolution, or (c) different discrete and isolated aqueous alteration environments.

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